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THIS QUERY FORM MUST BE RETURNED WITH ALL PROOFS FOR CORRECTIONS

AU1) Please provide the department/unit (if any) in affiliations *, †, and ‡.

AU2) Please check the disclosure statement introduced.

AU3) Please note that “ES” has been defined as “effect size.”

AU4) Please provide city name for the manufacturer “ProMedvi.”

AU5) Please consider rephrasing “Rittweger³⁵ identified time ...” for more clarity.

AU6) Please check edits to the sentence “There was a significant difference”

AU7) Please check if edits to the sentence “This theory has also been ...” retain the intended meaning.

AU8) Please clarify if the column “Treatment Group” containing “1. Control” can be deleted in Tables 3 and 4, as the same is explained in the footnote. Also clarify if the numbers preceding the treatment group “2. Vibration and wobble” and “3. Wobble” can be deleted.

Six-Week Combined Vibration and Wobble Board Training on Balance and Stability in Footballers With Functional Ankle Instability

Ross Cloak, MPhil,* Matthew Wyon, PhD,† Alan Nevill, PhD,‡ and Stephen Day, PhD§

Objective: To compare the effectiveness of a combination of vibration and wobble board training against wobble board training alone in footballers suffering from functional ankle instability (FAI).

Design: A 2 × 3 prefactorial–postfactorial design.

Setting: University research laboratory.

Participants: Thirty-three male semiprofessional footballers with self-reported unilateral FAI were randomly assigned in 3 groups: vibration and wobble board (mean age 22.2 years), wobble board (mean age 22.7 years), and control (mean age 23.1 years).

Interventions: Participants in each intervention group performed a 6-week progressive rehabilitation program using a wobble board, either with or without the addition of vibration stimulus.

Main Outcome Measures: Absolute center of mass (COM) distribution during single-leg stance, modified star excursion balance test (SEBT) reach distances, and single-leg triple hop for distance (SLTHD) were measured before and after 6-week intervention.

Results: Combined vibration and wobble board training resulted in reduced COM distribution [$P \leq 0.001$, effect size (ES) = 0.66], increased SEBT reach distances ($P \leq 0.01$ and $P \leq 0.002$, ES = 0.19 and 0.29, respectively), and increased SLTHD ($P \leq 0.001$, ES = 0.33) compared with wobble board training alone during the course of the 6-week training intervention.

Conclusions: Combined vibration and wobble board training improves COM distribution, modified SEBT scores and SLTHD among footballers suffering FAI, compared with wobble board training alone.

Key Words: vibration, functional instability, balance, injury

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The authors report no conflicts of interest.

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INTRODUCTION

Ankle inversion sprain is a common injury in both sportsmen and physically active individuals, with recurrence rates for this type of injury being reported to be as high as 80%.¹ Football is a complex contact sport associated with high levels of injury risk.² Of these, ankle injuries are commonly reported accounting for between 11% and 18% of all injuries, the majority of which are sprains.³

The most common complication after ankle sprain is functional instability,⁴ which is a condition characterized by repetitive episodes of “giving way” and/or incidence of recurrent ankle sprain.⁵ Functional ankle instability (FAI) can be considered as a multifactorial condition involving neurological, muscular, and sensorimotor factors, all contributing to a deficit in balance and muscle function.⁶ These impairments have been shown to include postural control,⁷ dynamic balance,⁸ and muscle function.⁹ Arnason et al¹⁰ identified that previously sprained ankles in footballers had as much as a 5-fold increase in injury risk in comparison with their uninjured counterparts, indicating not only significant instability after ankle sprain but also the necessity for a more effective rehabilitation program.

Rehabilitation using wobble board techniques has been popular among clinicians for a number of years,¹¹ particularly among football populations.¹² Although research suggests an improvement in symptoms of ankle instability with the intervention of wobble board training,¹³ others contradict this claim indicating no significant improvement in balance or muscle function.^{14,15} A meta-analysis by Van der Wees et al¹⁶ indicated that rehabilitation programs based on wobble board proprioceptive exercises could be considered clinically effective in ankle rehabilitation. This assumption, however, has been challenged on the basis that wobble board training alone does not actually target ankle proprioception deficits.¹⁷ Kiers et al¹⁷ proposed that training on unstable surface was alone not sufficient to stimulate ankle proprioceptors but did highlight the sensitivity of ankle muscle spindles to vibration stimulus and suggest that muscle spindles are key to ankle proprioception and overall body orientation. These results suggest that clinicians need to consider more effective exercises in ankle rehabilitation and warrant further investigation into the inclusion of vibration stimulus.

Whole-body vibration training (WBVT) is a method that has been recently introduced as a rehabilitative tool among clinicians.^{18–20} It has been hypothesized that the transmission of mechanical oscillations from the vibrating platform may lead to

physiological changes in muscle spindles, joint mechanoreceptors, higher brain activity, and hence strength and power properties.¹⁸ The proposed physiological reasons behind these changes have been attributed to stimulation of primary afferent (Ia, IIa) endings of the muscle spindles as identified with the reflex muscle contraction known as tonic vibration reflex.²¹ A reduction in motor unit recruitment thresholds and altered motor neuron excitability have also been suggested as mechanisms for the above physiological improvements.²² Whole-body vibration training has typically taken place on a stable platform; recently, however, a vibration system has been incorporated into a wobble board (Vibrosphere; ProMedvi, Sweden), which claims to incorporate the benefits of traditional vibration therapy with the added advantage of increased postural demand. This method of training has been shown to be successful in improving certain balance parameters in elderly populations.¹⁹ There was, however, no direct comparison with wobble board exercise alone, therefore the true contribution of the vibration component is difficult to ascertain.

The purpose of the present research therefore was to examine the effect of 6-week combined vibration and wobble board training (Vibrosphere; ProMedvi) against wobble board training alone on absolute center of mass (COM) distribution during single-leg stance, modified star excursion balance test (SEBT), and single-leg triple hop for distance (SLTHD) in footballers suffering from FAI. We hypothesize an improvement in balance with use of a combination of vibration and wobble board training based on previous literature,¹⁹ although it is unclear whether this will be of greater effect than wobble board training alone.

METHODS

Participants

Thirty-three male amateur football players volunteered to take part in the study (Table 1). The inclusion criteria for participation in this study were self-reported unilateral chronic ankle instability, including a history of more than 1 lateral ankle sprain within the past 2 years, and recurrent feeling of “giving way.” Participants were eligible for the study if their Cumberland ankle instability tool score (CAIT) was greater than 23. The tool is a questionnaire with 9 adjectival scale questions that generates a score between 0 and 30 and has high reliability and discriminative validity.²³ Scores ≤ 23 indicate FAI. Exclusion criteria for all participants included an ankle injury during the previous 6 weeks, any balance or vestibular disorder, any history of lower limb breaks or fractures, previous ankle, knee, or hip surgery, and/or current head injury. Participants also presented

negative results in the anterior drawer test, which assesses the integrity of the anterior talofibular ligament and of talar tilt test that assess the calcaneofibular ligament integrity.²⁴

All participants gave written informed consent, and the study was approved by the local ethics committee. According to the results of the CAIT (Table 1), participants were randomly assigned (using the closed envelope technique) to the vibration and wobble board training group (Vibrosphere; ProMedvi), wobble board training alone, or the control group. The latter were asked to continue normal activity.

Data Collection

Centre of Mass Distribution

Participants were asked to remain as motionless as possible while standing on their test leg, on the RSscan pressure mat (RSscan, Ipswich, United Kingdom) as the inability to maintain quiet stance during single-leg standing has been associated with ankle instability.²⁵ The use of a pressure mat to assess changes in COM distribution had been previously suggested as a valid and reliable assessment tool.²⁶ Participants performed all tests with their eyes open, hands on hips, and their non-weight-bearing leg flexed at 90-degree angle at the knee. All participants performed the test barefoot to eliminate the effect of the shoe type.²⁷ Participants performed one 10-second practice trial, followed by three 30-second testing trials. Participants rested 20 seconds between trials as suggested in previous research.⁷ Trials were repeated if the participants lost balance, hopped, or touched down on the non-weight-bearing leg. The investigators recorded the number of retrials, and no statistical significance was shown between groups. Center of mass distribution represented the maximum distance of sway area (in square centimeters) of the participants COM during the given time.⁷ The average of 3 trials was recorded.

Modified Star Excursion Balance Test

The SEBT has been shown to have a strong intratester and intertester reliability.²⁸ Performance of all 8 reach directions, however, was seen as unnecessary when evaluating deficits related to FAI because of considerable redundancy among the reach directions reported.⁸ Therefore, the participants performed the anterior, posterior medial, and posterior lateral SEBT directions that have been shown to be the most effective in assessing dynamic balance in participants with FAI.^{8,29} Each subject performed 3 practice trials in each of the 3 directions on identified leg followed by 5 minutes of rest before recording began. Participants then performed 3 trials in each direction. Ten seconds of rest were provided between individual reach trials.³⁰

TABLE 1. Participant Characteristics

Group	N	Age, yr Mean (SD)	Mass, kg Mean (SD)	Height, cm Mean (SD)	Affected Limb		CAIT Score
					Right	Left	
Vibration and wobble board	11	22.2 (0.7)	78.3 (7.7)	174.5 (7.8)	6	5	18.1 (0.9)
Wobble board	11	22.7 (1.2)	73.9 (4.7)	171.2 (5.4)	7	4	17.4 (1.4)
Control	11	23.1 (1.1)	77.5 (7.0)	176.5 (9.0)	7	4	17.9 (1.3)

The participants performed the SEBT while standing barefoot on their unstable ankle in a grid laid on the floor with 3 lines extending at 45-degree increments from the center of the grid. Reach distances were measured from the center of the grid, divided by leg length, and multiplied by 100 to calculate reach distance as a percentage of leg length (% MAXD) to normalize data.³¹

Single-Leg Triple Hop for Distance

Triple hop for distance is a valid clinical tool for assessing strength and power characteristics in healthy athletes, while tasking balance components.³² A standard cloth tape measure was fixed to the ground, perpendicular to a starting line. Participants stood on the designated testing leg, with the great toe on the starting line. They performed 3 consecutive maximal hops forward on the affected limb (arm swing was allowed). The investigator measured the distance hopped from the starting line to the point where the heel struck the ground upon completing the third hop.³³

All participants were allowed 1 to 3 practice trials (self-selected). A test trial was repeated if the participant was unable to complete a triple hop without losing balance and contacting the ground with the opposite leg. Number of practice trials and failed trials were recorded by the investigators, and no statistical relationship was highlighted, either in relation to performance or differences between groups. The maximum distance achieved during the 3 trials was recorded in centimeters and used for analysis. All participants wore low-cut athletic footwear during the test.³²

Combined Vibration and Wobble Board Training

The training methodology was based on the recommendation by Ergen and Ulkar¹² for rehabilitation training in football players suffering from functional deficits after ankle injury. Both training groups exercised twice a week for 6 weeks. Each training session was supervised by one of the members of the research team. Table 2 indicates the training undertaken over the 6-week duration. To ensure comparability between VibroSphere and wobble board training groups, the Vibrosphere (ProMedvi) was used by both the training groups. The researchers took this view to maintain validity when comparing both groups, so any differences could not be associated with using a different wobble board or training protocol. The function pads, which are designed to reduce stability and increase difficulty while on the Vibrosphere (ProMedvi), were also used for both groups (Figure 1). Hertz and time progression was used to provide progressive overload as with previous research advocating these frequencies.³⁴ Rittweger³⁵ identified time under tension, or in the case of vibration training time under exposure, as key to progressive overload as well as frequency. Task difficulty of each exercise was manipulated as recommended by Ergen and Ulkar.¹² These recommendations included a progressive increase in task difficulty and volume of exercises by manipulating exposure time, external resistance (with the addition of an external load), and finally a sport-specific component in the final weeks of the intervention.

Data Analysis

The 3 dependent variables were the COM distribution, SLTHD, and SEBT, the latter of which was normalized as a percentage of subject's leg length (including anterior, posterior medial, and posterior lateral distances). All data were analyzed using a 2-way analysis of variance (ANOVA) with repeated measures, with one between-subject factor [treatment group (3 levels); combined wobble board and vibration vs wobble board vs control] and one within-subjects factor (time; pretraining vs posttraining). Bonferroni post hoc tests and pairwise multiple comparisons were used to determine which change values (difference between pretraining and posttraining) differed between the treatment groups. These change values were analyzed using a 1-way ANOVA, with change values as the dependent variable and the 3 treatment groups as the grouping factor in the ANOVA. An alpha level of $P < 0.05$ was determined to be significant for all statistical comparisons.

RESULTS

Center of Mass Distribution and Single-Leg Triple Hop for Distance Results

There was a significant difference in COM distribution because of the main effect "time" [$F(1, 30) = 57.99, P = 0.001$] with a large effect size (ES) (partial eta squared = 0.66). Overall differences in COM distribution because of the main effect "treatment group" were not significant [$F(2, 30) = 2.57, P = 0.094$]. However, a significant group-by-time interaction was observed [$F(2, 30) = 6.74, P = 0.004$], indicating that the changes in COM distribution from preintervention to postintervention varied significantly between the 3 groups. This interaction effect is illustrated in Figure 2, which includes standard error bars. Post hoc comparisons using Bonferroni test indicated that the changes in COM distribution preintervention to postintervention of the control group differed significantly from the combined vibration and wobble board group ($P < 0.001$) (Table 2). There was a significant difference in SLTHD because of the main effect "time" [$F(1, 30) = 15.02, P = 0.001$] with a medium ES (partial eta squared = 0.33).

Overall differences in SLTHD because of the main effect "treatment group" were not significant [$F(2, 30) = 1.13, P = 0.336$]. However, a significant group-by-time interaction was observed [$F(2, 30) = 10.52, P = 0.001$], indicating that the changes in SLTHD from preintervention to postintervention varied significantly between the 3 groups. This interaction effect is illustrated in Figure 3, which includes SE bars. Post hoc comparisons using Bonferroni test indicated that the changes in SLTHD preintervention to postintervention of the control group differed significantly from the combined vibration and wobble board group ($P < 0.001$) (Table 3).

Modified Star Excursion Balance Test Results

There was a significant difference in SEBT anterior and posterior lateral reach distances (%MAXD) distribution because of the main effect "time" [$F(1, 30) = 6.97, P = 0.01$ and $F(1, 30) = 11.99, P = 0.002$] with a small ES (partial eta squared = 0.19 and 0.29, respectively). Overall differences in SEBT anterior and posterior lateral reach distances (%MAXD)

TABLE 2. Six-Week Training Program for VibroSphere and Wobble Group

Exercise	Difficulty	Function Pad	Time	Hertz
Week 1				
Standing on one leg	Static hands on hips	Dark blue-soft 2-intermediate	2 × 45 each leg	30
Heel raises on one leg	Isometric with support	Dark blue-soft 2-intermediate	2 × 45 each leg	30
Single-leg step ups	Hands on hips	Dark blue-soft 2-intermediate	2 × 45 each leg	30
Single-leg straight leg dead lifts	Hands on hips	Dark blue-soft 2-intermediate	2 × 45 each leg	30
Week 2				
Standing on one leg	Static hands on hips	Dark blue-soft 2-intermediate	2 × 45 each leg	30
Heel raises on one leg	Isometric with support	Dark blue-soft 2-intermediate	2 × 45 each leg	30
Single-leg step ups	Hands on hips	Dark blue-soft 2-intermediate	2 × 45 each leg	30
Single-leg straight leg dead lifts	Hands on hips	Dark blue-soft 2-intermediate	2 × 45 each leg	30
Week 3				
Standing on one leg	3-kg medicine ball above head	Red-soft 3-difficult	2 × 60 each leg	35
Heel raises on one leg	Isometric with support	Red-soft 3-difficult	2 × 60 each leg	35
Single-leg step ups	3-kg medicine ball above head	Red-soft 3-difficult	2 × 60 each leg	35
Single-leg straight leg dead lifts	3-kg medicine ball in hands	Red-soft 3-difficult	2 × 60 each leg	35
Week 4				
Standing on one leg	3-kg medicine ball above head	Red-soft 3-difficult	2 × 60 each leg	35
Heel raises on one leg	Isometric with support	Red-soft 3-difficult	2 × 60 each leg	35
Single-leg step ups	3-kg medicine ball above head	Red-soft 3-difficult	2 × 60 each leg	35
Single-leg straight leg dead lifts	3-kg medicine ball in hands	Red-soft 3-difficult	2 × 60 each leg	35
Week 5				
Standing on one leg	Volley ball back to partner	Blue-challenging fitness pad	2 × 75 each leg	40
Heel raises on one leg	Isometric with support	Blue-challenging fitness pad	2 × 75 each leg	40
Single-leg step ups	3-kg medicine ball above head	Blue-challenging fitness pad	2 × 75 each leg	40
Single-leg straight leg dead lifts	3-kg medicine ball in hands	Blue-challenging fitness pad	2 × 75 each leg	40
Week 6				
Standing on one leg	Volley ball back to partner	Blue-challenging fitness pad	2 × 75 each leg	40
Heel raises on one leg	Isometric with support	Blue-challenging fitness pad	2 × 75 each leg	40
Single-leg step ups	3-kg medicine ball above head	Blue-challenging fitness pad	2 × 75 each leg	40
Single-leg straight leg dead lifts	3-kg medicine ball in hands	Blue-challenging fitness pad	2 × 75 each leg	40

Wobble board group completed exercises in the absence of vibration.

because of the main effect “treatment group” were not significant [$F(2, 30) = 0.62$, $P = 0.545$ and $F(2,30) = 4.937$, $P = 0.140$]. However, a significant group-by-time interaction was observed for SEBT anterior reach distance [$F(2, 30) = 8.05$, $P = 0.002$] and SEBT posterior lateral reach distance [$F(2,30) = 5.78$,

$P = 0.008$], indicating that the changes in SEBT anterior and posterior lateral reach distances from preintervention to postintervention varied significantly between the 3 groups. This interaction effect is illustrated in Figures 4 and 5, which include SE bars. Post hoc comparisons using Bonferroni test

F4 – F5



FIGURE 1. Vibrosphere (ProMedvi) training device and function pads.

indicated that the changes in SEBT anterior and posterior lateral reach distances preintervention to postintervention of the control group differed significantly from the combined vibration and wobble group ($P < 0.001$) (Table 4). There was no significant group-by-time interaction reported between treatment groups for posterior medial reach distance (Table 4).

DISCUSSION

When interpreting the results of the present study, it should be remembered that both Vibrosphere (ProMedvi) and

wobble board groups did identical exercises on identical apparatus with the addition of vibration in the former. With this in mind, the results suggest that the addition of vibration provided extra benefit in SLTHD, COM distribution, and SEBT anterior/posterior scores. Vibration training has previously been suggested as a rehabilitation method among researchers; however, none of these studies have looked at the treatment of FAI within athletic populations, concentrating more on fall prevention strategies among the elderly and ACL reconstruction patients.^{18–20,36,37} The use of a combination of a vibration device built into a wobble board has been

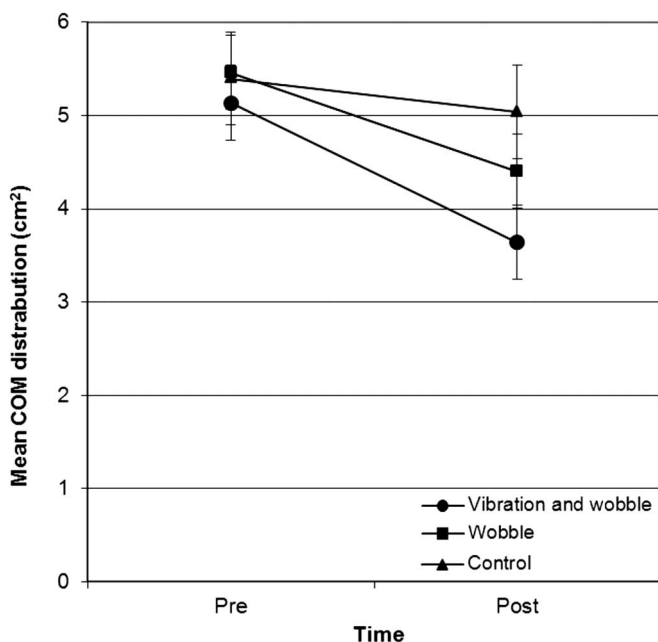


FIGURE 2. Center of mass distributions between treatment groups over time.

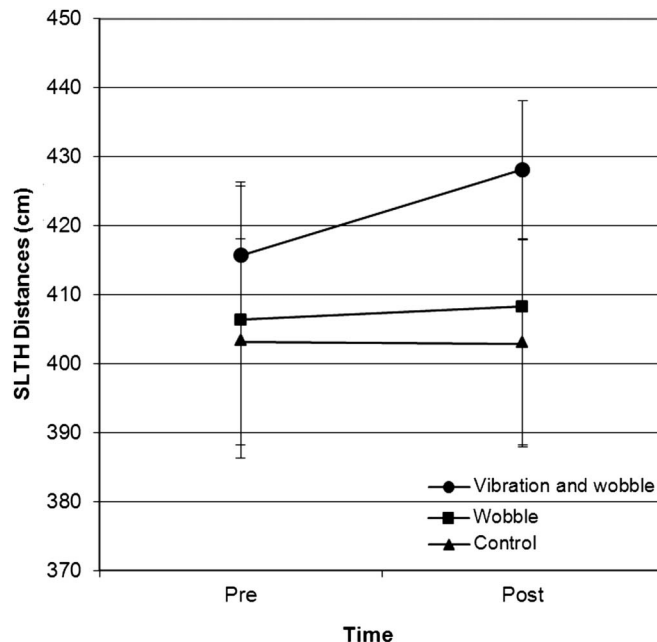


FIGURE 3. Single-leg triple hop for distance between groups over time.

AU8 TABLE 3. Center of Mass Distribution and SLTHD Results

Treatment Group	Treatment Group	Mean Difference	Significance	95% Confidence Interval	
				Lower	Upper
Pairwise comparisons COM distribution (cm ²)					
1. Control	2. Vibration and wobble	−1.14	0.001*	−1.93	−0.35
	3. Wobble	−0.70	0.09	−1.49	0.09
Pairwise comparisons SLTH distance (cm)					
1. Control	2. Vibration and wobble	−12.73	0.001*	−20.25	−5.20
	3. Wobble	−2.18	1.00	−9.71	5.35

Bonferroni post hoc test was performed, and the results were compared with the control group.

*Significance $P < 0.05$.

investigated previously.¹⁹ Trans et al¹⁹ used an 8-week training cycle on a Vibrosphere (ProMedvi) to assess strength and proprioception in elderly females suffering knee osteoarthritis. An improvement was shown for proprioception; however, no significant strength gains were reported. Although comparisons are difficult because of the participant pool, the reasoning behind differing effects in terms of strength increases may be due to the exercise routines being static knee flexion holds and the participants being a sedentary elderly population.¹⁹ Both the current research and the study by Trans et al,¹⁹ however, do conclude that the training device improves balance and strength indices over a relatively short period and number of sessions.

The COM distribution and SEBT improvements may also be associated with the benefits of vibration training. It has been well documented that the input of proprioceptive pathways (Ia, IIa, and IIb) are used in the production of isometric forceful contractions.³⁸ During WBVT, it has been

reported that these pathways are strongly stimulated.³⁹ The vibratory stimulus activates the sensory receptors that result in muscle contraction. The increase in SLTHD after 6 weeks of training, and thus after extensive sensory stimulation, might be as a result of a more efficient use of the positive proprioceptive feedback loop in the generation of intramuscular force production and isometric control.³⁹ The present study suggests that the combination of wobble board and vibration training may target not only the local muscles, such as tibialis anterior, peroneus longus, and gastrocnemius, but also possibly the core muscle groups leading to improved movement efficiency and coping with the demands of the balance tasks.⁴⁰ This could explain the improvement seen in COM distribution and SEBT. This theory has also been supported by previous research, which indicates that improvements in SEBT may be achieved through increased abdominal activation,⁴¹ highlighting the importance of rehabilitation within unstable ankle populations concentrating on a whole kinetic chain exercises, not just the

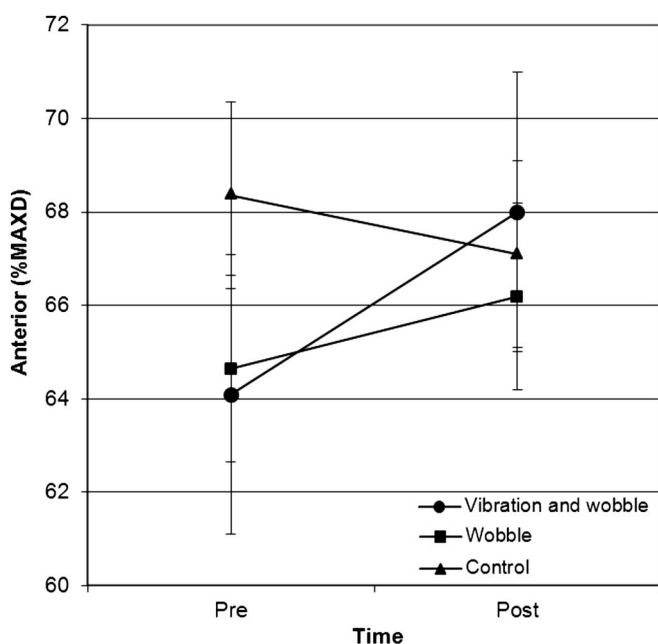
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FIGURE 4. Star excursion balance test anterior %MAXD reach distance between groups over time.

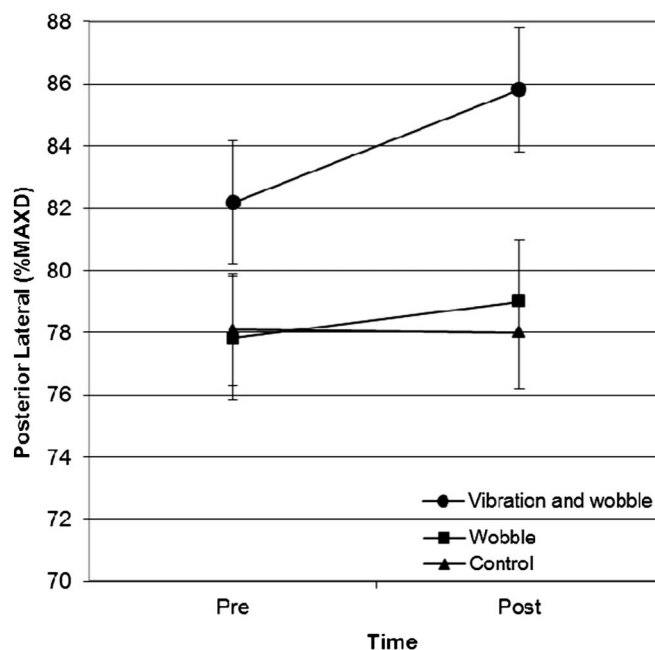


FIGURE 5. Star excursion balance test posterior lateral %MAXD reach distance between groups over time.

TABLE 4. Modified SEBT Mean and SD of Normalized Reach Distances

Treatment Group	Treatment Group	Mean Difference	Significance	95% Confidence Interval	
				Lower	Upper
Pairwise comparisons of anterior reach distance					
1. Control	2. Vibration and Wobble	5.18	0.001*	1.90	8.46
	3. Wobble	2.81	0.11	−0.46	6.10
Pairwise comparisons of posterior medial reach distance					
1. Control	2. Vibration and Wobble	1.55	0.26	−0.69	3.78
	3. Wobble	0.73	1.00	−1.51	2.96
Pairwise comparisons of posterior lateral reach distance					
1. Control	2. Vibration and Wobble	3.73	0.001*	−0.69	3.78
	3. Wobble	1.27	0.78	−1.51	2.96

Reach distance is centimeter per leg length in centimeters.

Bonferroni post hoc test was performed, and the results were compared with the control group.

*Indicates significance $P < 0.05$.

peripheral site of the injury,⁴² such as balance/vibration stimulation, mediated by a progressive set of exercises used in the present research. The current research, however, acknowledges that any such assumptions from the present results would need confirmation through future research using electromyography and motion analysis.

Vibration training has been well documented as a training method for improving neuromuscular properties of skeletal muscle, such as strength and power indices.^{39,43–45} Such structural changes are not only mediated by acute intramuscular factors by increasing muscle size and structure through hypertrophy.⁴⁶ But given the duration of the present study, the more likely reason behind the improvement in muscle function was neural adaptation to primary afferent (Ia, IIa) endings of the muscle spindles,²¹ a reduction in motor unit recruitment thresholds, and altered motor neuron excitability,²² thus allowing for a more co-ordinated and forceful activation during different permutations of movement.⁴⁷ This knowledge of vibration training and neuromuscular adaptation may help us to understand the above findings among the Vibrosphere (ProMedvi) training group, particularly among the SLTHD; however, as with previous studies,⁴⁷ the absence of EMG profiling or muscle biopsies means any such conclusion are difficult. However, on the basis of the evidence set forth above, it could be assumed that such adaptations have occurred.

The current research acknowledges that the present variables are not sole predictors of injury, and future longitudinal studies are needed to assess how long these positive results continue and whether this information correlates with reinjury risk. This is particularly important for footballers as by assessing if the intervention itself has reduced injury occurrence, we can begin to reduce one of the main contributory factors to injury risk in football, that of a previous or recurrent history of ankle injury.¹⁰ The researchers also acknowledge that in the current cost–benefit ratio environment, many clinicians face with any new equipment. The relatively small ES (partial eta squared = 0.19 and 0.29) among the SEBT anterior and posterior scores highlights the

need for further research. It is recommended this future research is completed using the Vibrosphere (ProMedvi) in a multi-intervention setting, before the clinical significance of the device can be fully ascertained.

CONCLUSIONS

Six weeks of progressive wobble board and vibration training significantly improved COM distribution, SEBT, and SLTHD in comparison with wobble board training alone. Combined wobble board and vibration training would seem to be beneficial in football players suffering FAI.

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